Cepheids/ Variable Stars

A **Cepheid** is a member of a class of very luminous variable stars. The strong direct relationship between a Cepheid variable's luminosity and pulsation period, secures for Cepheids their status as important standard candles for establishing the Galactic and extragalactic distance scales.

Cepheid variables are divided into several subclasses which exhibit markedly different masses, ages, and evolutionary histories: **Classical Cepheids**, **Type II Cepheids**, **Anomalous Cepheids**, and **Dwarf Cepheids**. Failure to distinguish these different subclasses in the early-to-mid 20th century resulted in significant problems with the astronomical distance scale.

The term *cepheid* originates from Delta Cephei in the constellation Cepheus, the first star of this type identified, by John Goodricke in 1784.

Classes

Classical Cepheids (also known as Population I Cepheids, Type I Cepheids, or Delta Cephei variables) undergo pulsations with very regular periods on the order of days to months. Classical Cepheids are population I variable stars which are 4–20 times more massive than the Sun, and up to 100,000 times more luminous. Cepheids are yellow supergiants of spectral class F6 – K2 and their radii change by millions of kilometers during a pulsation cycle.

Classical Cepheids are used to determine distances to galaxies within the Local Group and beyond, and are a means by which the Hubble constant can be established. Classical Cepheids have also been used to clarify many characteristics of our galaxy, such as the Sun's height above the galactic plane and the Galaxy's local spiral structure.

Type II Cepheids (also termed Population II Cepheids) are population II variable stars which pulsate with periods typically between 1 and 50 days. Type II Cepheids are typically metal-poor, old (~10 billion years), low mass objects (~half the mass of the Sun). Type II Cepheids are divided into several subgroups by period. Stars with periods between 1 and 4 days are of the BL Her subclass, 10–20 days belong to the W Virginis subclass, and stars with periods greater than 20 days belong to the RV Tauri subclass.

W Virginis variables are a subclass of Type II Cepheids which exhibit pulsation periods between 10–20 days, and are of spectral class F6 – K2.

They were first recognized as being distinct from classical Cepheids by Walter Baade in 1942, in a study of Cepheids in the Andromeda Galaxy that proposed that stars in that galaxy were of two populations.

Type II Cepheids are used to establish the distance to the Galactic center, globular clusters, and galaxies.

History

On September 10, 1784 Edward Pigott detected the variability of Eta Aquilae, the first known representative of the class of Classical Cepheid variables. However, the namesake for classical Cepheids is the star Delta Cephei, discovered to be variable by John Goodricke a few months later.

A relationship between the period and luminosity for classical Cepheids was discovered in 1908 by **Henrietta Swan Leavitt** in an investigation of thousands of variable stars in the Magellanic Clouds. She published it in 1912 with further evidence.

In 1915 Harlow Shapley used Cepheids to place initial constraints on the size and shape of the Milky Way, and of the placement of our Sun within it.

In 1924 Edwin Hubble established the distance to Classical Cepheid variables in the Andromeda Galaxy, and showed that the variables were not members of the Milky Way. That settled the Island Universe debate which was concerned with whether the Milky Way and the Universe were synonymous, or was the Milky Way merely one in a plethora of galaxies that constitutes the Universe.

In 1929 Hubble and Milton L. Humason formulated what is now known as Hubble's Law by combining Cepheid distances to several galaxies with Vesto Slipher's measurements of the speed at which those galaxies recede from us. They discovered that the Universe is expanding

In the 1940s Walter Baade recognized that Cepheids actually consist of at least two separate populations (classical Cepheids & Type II Cepheids). Classical Cepheids are younger and more massive population I stars, whereas Type II Cepheids are older fainter population II stars. Classical Cepheids and Type II Cepheids follow different period-luminosity relationships. The luminosity of Type II Cepheids is, on average, less than classical Cepheids by about 1.5 magnitudes (but still brighter than RR Lyrae stars). Initial studies of Cepheid variable distances were complicated by the inadvertent admixture of classical Cepheids and Type II Cepheids.[24] Walter Baade's seminal discovery led to a fourfold increase in the distance to M31, and the extragalactic distance scale. RR Lyrae stars were recognized fairly early (by the 1930s) as being a separate class of variable, due in part to their short periods.

Uncertainties in Cepheid determined distances

Chief among the uncertainties tied to the Classical and Type II Cepheid distance scale are: the nature of the period-luminosity relation in various passbands, the impact of metallicity on both the zero-point and slope of those relations, and the effects of photometric contamination (blending) and a changing (typically unknown) extinction law on Cepheid distances. All these topics are actively debated in the literature.

These unresolved matters have resulted in cited values for the Hubble constant (established from Classical Cepheids) ranging between 60 km/s/Mpc and 80 km/s/Mpc. Resolving this discrepancy is one of the foremost problems in astronomy since the cosmological parameters of the Universe may be constrained by supplying a precise value of the Hubble constant.

Dynamics of the pulsation

The accepted explanation for the pulsation of Cepheids is called the **Eddington valve**, or **κ-mechanism**, where the Greek letter κ (kappa) denotes gas opacity. Helium is the gas thought to be most active in the process. Doubly ionized helium (helium whose atoms are missing two electrons) is more opaque than singly ionized helium. The more helium is heated, the more ionized it becomes. At the dimmest part of a Cepheid's cycle, the ionized gas in the outer layers of the star is opaque, and so is heated by the star's radiation, and due to the increased temperature, begins to expand. As it expands, it cools, and so becomes less ionized and therefore more transparent, allowing the radiation to escape. Then the expansion stops, and reverses due to the star's gravitational attraction. The process then repeats.

The mechanics of the pulsation as a heat-engine was proposed in 1917 by Sir Arthur Stanley Eddington (who wrote at length on the dynamics of Cepheids), but it was not until 1953 that S. A. Zhevakin identified ionized helium as a likely valve for the engine.

Examples

- Classical Cepheids include: Eta Aquilae, Zeta Geminorum, Beta Doradus, as well as the namesake Delta Cephei. The North Star (Polaris) is the closest classical Cepheid, although the star exhibits many peculiarities and its distance is a topic of active debate.
- Type II Cepheids include: W Virginis and BL Hercules.
- Dwarf Cepheids include: Delta Scuti, SX Phoenicis.

RR Lyrae variable

RR Lyrae variables are periodic variable stars, commonly found in globular clusters, and often used as standard candles to measure galactic distances.

This type of variable is named after the prototype, the variable star RR Lyrae in the constellation Lyra.

RR Lyraes are pulsating horizontal branch stars of spectral class A (and rarely F), with a mass of around half the Sun's. They are thought to have previously shed mass and consequently, they were once stars with similar or slightly less mass than the Sun, around 0.8 solar masses.

RR Lyrae stars pulse in a manner similar to Cepheid variables, so the mechanism for the pulsation is thought to be similar, but the nature and histories of these stars is thought to be rather different. In contrast to Cepheids, RR Lyraes are old, relatively low mass, metal-poor "Population II" stars. They are much more common than Cepheids, but also much less luminous. (The average absolute magnitude of an RR Lyrae is 0.75, only 40 or 50 times brighter than our Sun.) Their period is shorter, typically less than one day, sometimes ranging down to seven hours.

The relationship between pulsation period and absolute magnitude of RR Lyraes makes them good standard candles for relatively near objects, especially within the Milky Way. They are extensively used in globular cluster studies, and also used to study chemical properties of older stars.

Abundances and distribution

RR Lyrae stars were formerly called "cluster variables" because of their strong (but not exclusive) association with globular clusters; conversely, about 90% of all variables known in globular clusters are RR Lyraes. RR Lyrae stars are found at all galactic latitudes, as opposed to classical Cepheid variables, which are strongly associated with the galactic plane.

Several times as many RR Lyraes are known as all Cepheids combined; in the 1980s, about 1900 were known in globular clusters. Some estimates have about 85000 in the Milky Way.

Discovery and recognition

In surveys of globular clusters, these "cluster-type" variables were being rapidly identified in the mid 1890s, especially by E. C. Pickering.

Probably the first star of definitely RR Lyrae type found outside a cluster was Mu Leporis, discovered by J. Kapteyn in 1890.

The prototype star RR Lyrae was discovered prior to 1899 by Williamina Fleming, and reported by Pickering in 1900 as "indistinguishable from cluster-type variables".

From 1915 to the 1930s, the RR Lyraes became increasingly accepted as a class of star distinct from the Cepheids, due to their shorter periods, differing locations within the galaxy, and chemical differences from classical Cepheids, being mostly metal-poor, Population II stars.

RR Lyraes have proven difficult to observe in external galaxies because of their intrinsic faintness. (In fact, Walter Baade's *failure* to find them in the Andromeda galaxy led him to suspect that the galaxy was much farther away than predicted, to reconsider the calibration of Cepheid variables, and to propose the concept of stellar populations.) Using the Hubble Space Telescope in the 1980s, Pritchet & van den Bergh[3] found Lyraes in Andromeda's galactic halo and, more recently, in its globular clusters.

Subtypes

The RR Lyrae stars are conventionally divided into three main types following a classification of S.I. Bailey based on the shape of the stars' brightness curves:

- RRab, the majority type, which display steep rises in brightness of about 91%;
- RRc, a type with shorter periods and more sinusoidal variation of about 9%; and
- RRd, a rare type of double-mode pulsators.

New and upcoming developments

The Hubble Space Telescope has identified several RR Lyrae candidates in globular clusters of the Andromeda galaxy and has measured the distance to the prototype star RR Lyrae.

The Gaia mission is expected to greatly improve knowledge of RR Lyraes by providing homogeneous spectrographic information of a large population of such stars.